Comparison between Wet and Dry Anaerobic Digestions of Cow Dung under Mesophilic and Thermophilic Conditions

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Abstract

The objective of this research is to compare dry anaerobic digestion of cow dung for methane production with wet anaerobic digestion under mesophilic and thermophilic temperatures in batch cultures for 63 days. The results showed that a specific methane yield of 0.333 and 0.345 LCH_4/gVS_r was obtained at 35°C in the fermentation systems for a dilute ratio of 1:1 and 1:0, with a VS removal of 50.01%, and 56.33%, a COD removal of 54.99%, and 61.35%, respectively. When the fermentation systems was performed under 55°C, the specific methane yield was increased to 0.351 and 0.374 LCH_4/gVS_r, with a VS removal of 53.43% and 60.52%, and a COD removal of 58.37% and 65.36%, respectively. Though addition of water could promote start-up process and biodegradability of the substrate to some extent, the methane yields in the dry anaerobic digestion process were found comparable to the conventional wet anaerobic digestion process. Furthermore, the volume of the reactor was increased twice in the wet fermentation process (7.68% TS) of cow dung compared to the dry fermentation (15.18% TS) at the same loading rate. It was suggested that dry methane fermentation process was superior in energy recovery, saving resources and engineering investment compared with wet fermentation process.

Keywords

Dry Fermentation Process; Methane Yield; Organic Materials Removal

Introduction

Anaerobic methane fermentation process is an alternative to conventional manure and other organic waste management, alleviating health and environmental concerns, and converting organic residues by microbial consortia in an oxygen-free condition into two categories of valuable products (Jingura and Rutendo, 2009; Li *et al*., 2011; Lema and Omil, 2001). One of these, the biogas rich in methane content, is a renewable energy further used to produce green electricity, heat or as engine fuel. The other one is the digested substrate, commonly named slurry or digestate, which is usually used as organic fertilizer or soil conditioner. Though wet fermentation process of manure and other organic wastes for methane production have been widely used and well developed technology (Jingura and Rutendo, 2009), there are some remarkable problems with the process including larger fermenter size, requirement of liquid source, and slurry handling problem (Jha *et al*., 2010).

The dry methane fermentation process stabilizes the organic solid wastes without dilution or using limited amount of water. Conventional anaerobic fermenters require feed materials with total solids content below 10% while dry methane fermentation process can deal with above 10% total solids content in the feedstocks (Jha *et al*., 2011). Both types of fermentation process rely on the same principles and processes to biodegrade organic matters but the dry fermentation process offers great advantages like utilization of wastes in its produced form, no requirement of liquid source, high organic loading rate, smaller fermenter, no liquid effluent, no requirement of purification of effluent and the like (Pavan *et al*., 2000). Moreover, dry methane fermentation process eliminates need for additional liquid and is considered as capable of producing higher methane production per m^3 volume of the bioreactor. It would be more feasible for semiarid climates and places where it is difficult to access (Köttner, 2002). Therefore research on dry methane fermentation process has great importance to make a more efficient and feasible process to solve multifaceted and dreadful waste problem. This study was conducted to evaluate the mesophilic and thermophilic fermentation processes of cow dung for 63 days at two different initial concentrations of total solids in terms of energy recovery, organic materials removal, process parameters and digestate characteristics.

Materials and Methods

Experimental Set Up and Procedure

The experiments were carried out in four batch lab-reactors of 2.5 L effective volume with an internal diameter of 13 cm, and height of 25 cm. The reactors R1 and R3 were operated on 35±1^{o}C while 55±1^{o}C was employed for the reactors R2 and R4. Each reactor was fitted with four ports (FIG. 1). The two ports were fitted on the cover while other two ports were fitted on the side. One of the cover ports was used for measuring biogas production. The sample for analysis of biogas quality was also taken out from the same port. The other cover port was set aside as spare. One of the side ports was kept above 5 cm from the bottom. This port was used to take out the sample for the analysis of various parameters while pH meter was set up at the other side port. The samples were stored at -4^{o}C in a freezer before the analysis which generally performed within one week.

Characteristics of Feed Stocks

Cow dung was used as feedstocks in this study. It was thick slurry and obtained from a livestock farm in Harbin, China. The foreign materials like stone, wood, metal, straw, feather and other inorganic materials were manually removed from the cow dung. The average values of the physico-chemical characteristics of the manure and inoculum are shown in TABLE 1.

The cow dung, which had 15.98% TS, contained 134.62 gVS and 152.05 gCOD per kg of wet-manure. The ratio of COD to VS was 1.13. The high proportion of VS to TS (84.24%) depicts that a large fraction of the cow dung was biodegradable and could serve as an important feedstock for biogas production. The C/N ratio of the cow dung was found adequate (25.18) because it is often suggested that the C:N ratio in the substrate should be in between 20:1 to 30:1.

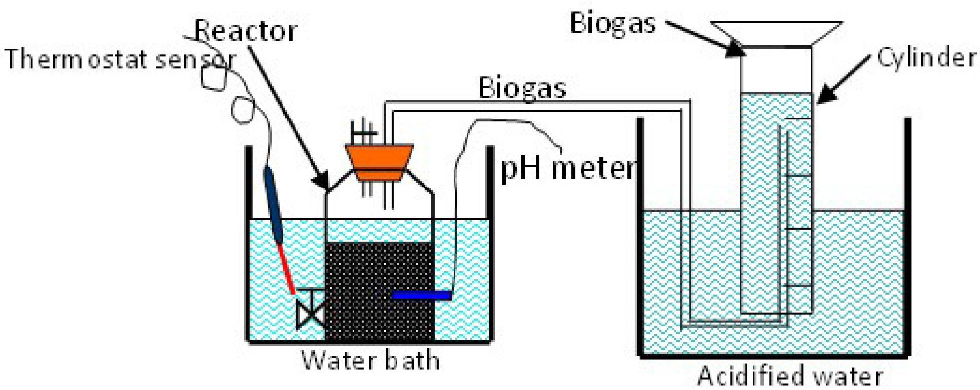

FIG.1 SCHEMATIC DIAGRAM OF THE REACTOR.

TABLE 1. CHARACTERISTICS OF SUBSTRATE AND INOCULANTS.

Type of analysis	Cow dung	Mesophilic inoculant	Thermophilic inoculant
pH	7.48	7.60	7.69
Total solid (g/kg)	159.80±0.8	107.81	111.80
Volatile solids (% of TS)	84.24±0.5	59.18	58.36
Chemical oxygen demand (g/L)	152.05±4	73.43	71.37
Soluble COD (g/L)	65.15±0.7	21.92	22.35
Total organic carbon (g/L)	40.58±1.3	15.43	14.58
Total phosphorus (g/L)	1.53±0.3	1.35	1.41
Total kjeldahl nitrogen (g/L)	2.97±0.6	2.35	2.64
Ammonia nitrogen (g/L)	1.34±0.1	1.20	1.46
Free ammonia (g/L)	0.04	0.05	0.22

TABLE 2. COMPOSITION AND CONDITION OF THE REACTORS.

Reactor	Composition			Temp. (^{o}C)	pH	TS (%)	VS (% TS)
	Cow dung	Water	Inoculant				
R1	1000	0	200	35±1	7.50	15.18±0.4	80.72±0.3
R2	1000	0	200	55±1	7.52	15.15±0.4	80.74±0.3
R3	1000	1000	200	35±1	7.73	7.68±0.3	82.23±0.2
R4	1000	1000	200	55±1	7.75	7.66±0.3	82.19±0.2

The digested slurry from the previous dry anaerobic digestion experiment of cow dung was utilized as inoculum. The cow dung was then inoculated with the digestate obtained from fermentation process of cow dung. The inoculant for mesophilic reactors was prepared by digestating cow dung anaerobically at 35±1^{o}C while 55±1^{o}C was employed to prepare the inoculant for the thermophilic reactors. These temperature-adopted inoculums provided the initial population of anaerobic microorganisms for initiating fermentation process in the system (Gacho *et al.*, 2010). In the fermentation process, the cow dung was fed into air-tight fermenter under specified environmental conditions. TABLE 2 shows the composition of the substrates in each reactor and the mean values of their physical-chemical characteristics. Each reactor contained 1 kg wet-substrate and 200 g inoculant. No other nutrients or chemical was fed into the reactors. For reactors R1 and R2, the cow dung was used in its produced form while for the reactor R3 and R4, the cow dung was diluted with equal amount of water on weight basis. As a result of this, the total solids in the feed of the reactors R1 and R2 was observed more than 15% while the total solids in the feed of the reactors R3 and R4 was noted less than 8%. It meant that the reactors R3 and R4 represented wet fermentation process of cow dung while the reactors R1 and R2 the dry fermentation process of cow dung. The simple calculation shows that dilution of the cow dung collected at 15% TS to 8% TS would need water which would be given over two times the original mass. This additional water would not only increase the size of the reactor to accommodate the added water but also would require a large quantity of heat to keep the slurry temperature high enough for bacterial activities. As the initial pH in all the reactors was measured in favourable range (7.50-7.75), it was not needed to adjust the pH before keeping it into the fermenter. Each fermenter was purged with nitrogen for 15-20 min to create complete anaerobic environment. The contents of the reactors were slowly shaken once daily for 2-3 min to create homogeneous substrate preventing stratification and formation of a surface crust and distributing microorganisms throughout the fermenter. During the fermentation period, fibrous materials have not been observed to float inside dry fermenters while the fibrous materials sometimes drifted on the top inside the wet reactors.

Analytical Methods

The physico-chemical parameters analyzed were temperature, pH, total solid (TS), volatile solid (VS), chemical oxygen demand (COD), soluble chemical oxygen demand (SCOD), volatile fatty acids (VFAs), total phosphorus (TP), total Kjeldahl nitrogen (TKN), total ammonia nitrogen and free ammonia. All the analytical determinations were performed according to the standard methods (APHA, 1995). All the tests were conducted in triplicate and mean values were reported. The pH of the mixtures was measured with a digital pH meter (Seven Multi SK40, Switzerland). The free ammonia was calculated using the previously reported formula (Østergaard, 1985). The yielded biogas was measured per day by downward water displacement method at atmospheric pressure using calibrated 1 or 2 litres cylindrical jar for each reactor. The constituents (CH_4, CO_2 and H_2) of the biogas were determined using Gas Chromatography (SP-6800A, Shandong Lunan Instrument Factory, China) equipped with a thermal conductivity detector and a 2 m stainless column packed with Porapak TDS201 (60-80 mesh). Nitrogen was employed as the carrier gas at a flow rate of 40 mL/min. The operation temperatures for the injection port, oven and detector all were 80°C. The cumulative methane production for each test was determined by summing daily methane production, which was calculated by timing daily biogas production with corresponding methane content minus the methane produced due to inoculum source. The samples taken from the batch culture reactor were centrifuged at 6,000 rpm for 15 min, and then acidified with hydrochloric acid and filtered through a 0.2 μm membrane for the analysis of VFAs and ethanol. The concentrations of the VFAs and ethanol were determined using a second gas chromatograph (SP6890, Shandong Lunan Instrument

Factory, China) equipped with a flame ionization detector and a 2 m stainless (5 mm inside diameter) column packed with Porapak GDX-103 (60/80 mesh). The operational temperatures of the injection port, the column and the detector were 220, 190 and 220℃, respectively. Nitrogen was used as carrier gas at a flow rate of 50 mL/min.

Results and Discussion

Evolution of pH, NH_3-N and VFAs

Four single-stage lab-batch reactors were tested during a period of 63 days to assess the effects of initial total solids content on anaerobic fermentation process of cow dung for methane production at the optimal mesophilic and thermophilic temperatures. The pH is regarded as the key indicator of operational stability. The initial pH of each input substrate in the digester was 7.50, 7.52, 7.73 and 7.75 for the digester labeled as R1, R2, R3 and R4, respectively. So this result was in agreement with a pH range of input mixture in the digester between 6.80 and 7.60, which is suitable for anaerobic microorganisms. Due to VFAs production of acidogenic bacteria during the start up phase as well as carbonic acid associated with the high concentrations of carbon dioxide gas, pH values in all the reactors were decreased upto 6.74, 6.80, 6.76 and 6.71 in the reactors R1-R4, respectively (FIG. 2a). Actually, the easily digestible fraction of organic matter, mainly carbohydrates, was hydrolyzed and converted to fatty acids rapidly. The presence of high CO_2 also lowered the pH in the digester. The equation for the effect of CO_2 on the pH is shown in the equation below:

$$H_2O + CO_2 \longrightarrow H_2CO_3 \longrightarrow H^+ + HCO_3^-$$

Variation in pH affected the fermentation process because the hydrogen ion concentration has direct influence on microbial growth. The ideal pH for methanogens ranges from 6.80 to 7.60, and their growth rate will be greatly reduced below pH 6.60. A pH less than 6.10 or more than 8.30 will cause poor performance and even the failure of a fermenter (Lay *et al*., 1997). So it is necessary to correct the unbalanced, low pH condition in a fermenter. The biogas process also becomes more sensitive towards increment of pH value because the concentration of free ammonia increases as pH value raises (Hansen *et al*., 1998). Therefore, in this study, pH was maintained in between 6.80 to 7.60 by adding 6 nmol NaOH or 6 nmol HCl during the fermentation period. The pH variation pattern observed was similar for all the tests.

The pH value did not drop off much lower because the substrates were able to buffer themselves and prevent the acidification occurrence due to proper alkalinity of cow dung to maintain optimal biological activity and stability of the fermentation system. The pH value for all the experiments began to rise gradually as the VFAs were consumed by methanogens and transferred to the methane. Furthermore, protein was hydrolysed and amino acid produced, could also finally cause pH increase. However, it was also observed that there was stable pH in all the reactors after five weeks.

The initial NH_3-N of each input substrate in the digester was 1.13, 1.16, 0.67 and 0.67 g/L for the reactor labeled as R1, R2, R3 and R4, respectively. In each treatment of this study, the accumulation of ammonia has been increased to some extent due to the hydrolysis of amino acids and proteins during the start up period. Afterwards, the concentration of ammonia was decreased since NH_3-N was used as nitrogen source for methanogens growth. It was again increased since the protein-containing hard biodegradable fraction began to hydrolyze after some days of the beginning of the digestion process. As a result, fluctuated ammonia variation patterns were observed for all the tests during the digestion period (FIG. 2b). Ammonia was regarded as a weak base that dissociates in water forming alkalinity:

$$NH_3 + H_2O \longrightarrow NH_4^+ + OH^-$$

At different concentrations, both species NH_3 and NH_4^+ are known to be inhibitory. The existence of high content of the free ammonia is more toxic for biogas process than the presence of ammonia nitrogen (Angelidaki and Ahring, 1993) because the specific growth rate of methanogenic bacteria is a function of the free ammonia concentration and decreases as the concentration of ammonia increases (Hansen *et al.*, 1998). The growth of acetate-utilizing bacteria has been started to inhibit 0.10-0.15 g/L (De Baere *et al.*, 1984) while H_2-utilizing methanogenic bacteria are inhibited at free ammonia concentrations higher than 1.20 g/L (Hansen *et al.*, 1998). The values of the calculated free ammonia for the bioreactors R1-R4 were determined in the range of 0.01-0.08, 0.02-0.23, 0-0.04 and 0.01-0.13 g/L, respectively (FIG. 2c), indicating no inhibition, occurred due to the presence of the free ammonia except partial inhibition in the reactor R2 (thermophilic dry anaerobic fermentation

process) and in R4 (only for the acetate-utilizing bacteria to some extent).

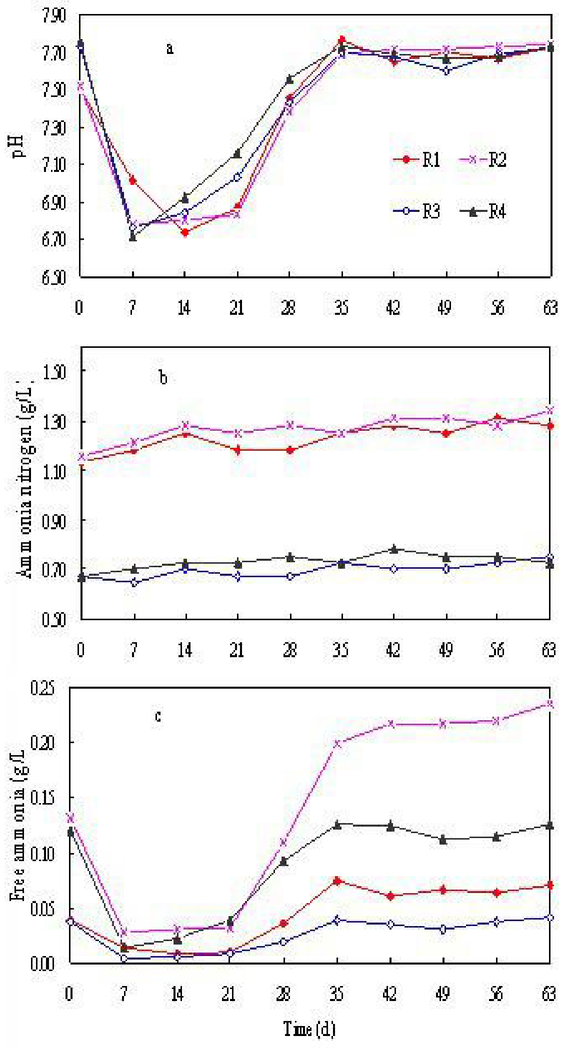

FIG. 2. VARIATION PATTERN OF (a) PH, (b) AMMONIA NITROGEN AND (c) FREE AMMONIA

VFAs are intermediate compounds in the metabolic pathway of anaerobic fermentation process of organic wastes for biogas production and usually produced due to the degradation of the complex organic polymers during hydrolysis and acidogenic stages. The conversion of VFAs has been treated as an indicator of the digestion efficiency but the high concentration of VFAs could cause microbial stress, which resulted in a decrease in pH, acidification, destroy methanogenic bacteria activity and led to failure of fermenter ultimately. As cow dung contains high percentage of carbohydrates and it is known to be easily and rapidly converted via hydrolysis to simple sugars and subsequently fermented to VFAs, the production of VFAs was increased rapidly after incubation of the fermenters in this study. The peak values of VFAs for the reactors R1-R4 were 8.02, 8.76, 5.26 and 5.91 g/L, respectively. The VFAs profile showed for all the reactors that VFAs concentrations increased as influent substrate concentrations increased (FIG. 3). Moreover, all the reactors showed high VFAs concentrations in the start up phase because of higher acidogenesis and lower methanogenic activities. The principal volatile acids formed were acetic, butyric and propionic acids. Acetic acid was the dominant volatile fatty acid and its presence was in the range of 54-75%, 63-83%, 63-80% and 59-77% in the reactors R1-R4, respectively. Furthermore, the acetic acid production rate was apparently higher than the acetic acid consumption rate during the start up period. The share of acetic acid was found slightly higher in thermophilic reactors than that in mesophilic reactors during the start up period. The higher concentration of VFAs during the start up period results in the increasing amount of ammonia within the limits which has insignificant influence on the hydrolysis and acidogenesis. The share of propionic and butyric acids observed was low because of the sufficient propionate- and butyric-degrading syntrophs which could rapidly convert propionic acid and butyric acid to acetic acid (Montero *et al.*, 2008). The degradation of propionate and butyrate by syntrophic acetogenic bacteria (e.g. syntropher wolinii, syntrophomonas wolfei) produced acetic acid that was subsequently degraded into methane and CO_2 by acetoclastic methanogens (Montero *et al.*, 2008). During methanogenic stage, the methanogens were in exponential growth phase and the acetic acid consumption rate was higher though hydrolysis and acidogenesis were still going on. The consumption rate of propionate was observed slower than that of butyrate because the oxidation of propionate to acetate is relatively more difficult. Therefore, as methanogenesis and methane gas yield have been increased, the VFAs concentrations were decreased. At the end of the processes, there were maximum quantity of VFAs remained in R1 followed by R2, R3, and R4, indicating the degradation rate of VFAs in dry fermenters slower than that of wet fermenters and thermophilic reactors as well as mesophilic reactors. No inhibitory concentration of VFAs was noted during the experiment (Ahring *et al.*, 1995). No high VFAs accumulation was detected due to perhaps acetatoclastic methanogens which could consume acetate quickly in the fermenters to yield methane and carbon dioxide.

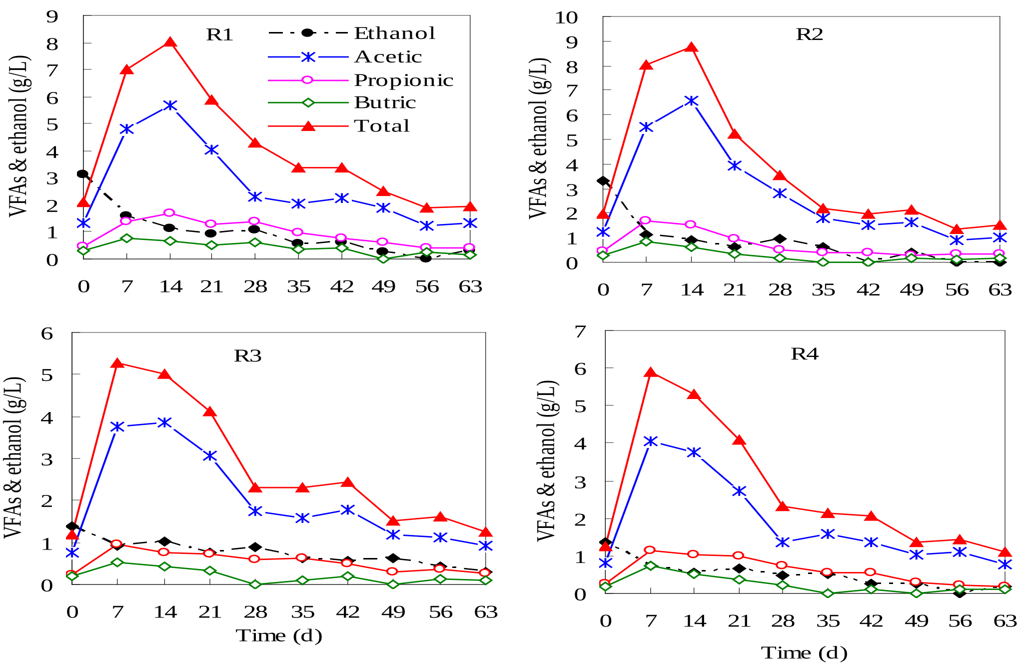

FIG. 3 EVOLUTION OF VFAS.

VFAs and alkalinity together are the good indicators to evaluate the process stability of the anaerobic reactor. As reported by the previous study (Zhao and Viraraghavan, 2004) if the ratio of VFAs to alkalinity exceeded 0.80, the inhibition of methanogens occurred. On contrary, other researches (Sánchez *et al.*, 2005; Malpei *et al.*, 1998) have stated that optimum ratio of VFAs to alkalinity should not be more than 0.40. FIG. 4 shows the variation in VFAs to alkalinity ratio. The ratio varied in between 0.20 to 0.40 except during start up period. Though the ratio was noted upto 0.8 in the start up phase, the process seemed stable because no accumulation of VFAs and no drastic fall in pH were observed.

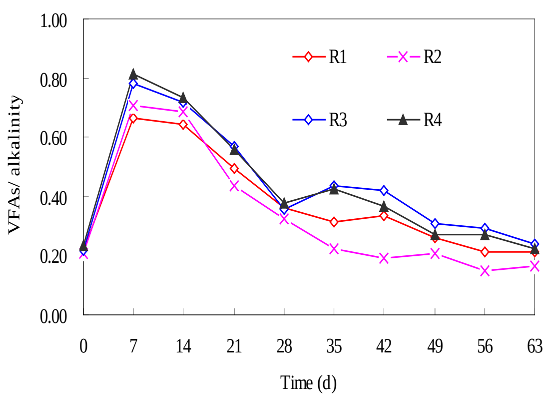

FIG. 4 VFAS TO ALKALINITY RATIO.

Biogas Generation and Methane Content

Mesophilic Fermentation Process

FIG 5 shows the daily biogas production, methane content and cumulative methane yield for all the mesophilic and thermophilic reactors during the fermentation period. The biogas generation was started after seeding. The initial biogas production was due to readily biodegradable organic matter in the substrates and presence of methanogens from the inoculum. The low methane content was the result of the occurrence of fermentative stage and acid-forming stage. Fermentative bacteria and acid-forming bacteria were predominant in these periods. The biogas yield was then increased because the growth of methanogenic bacteria lifted and became established in the fermenter to use end products from the acid forming bacteria digestion to produce methane. In this stage, methanogenic bacteria were predominant. After achieving peak values, the biogas production began to decline. It was found that during the fermentation process, the soluble organic matter was converted to the gas, and the insoluble fibrous matter began dissolving. As methane gas has low solubility in water, it was rapidly discharged from the system resulting in stabilization of the waste. The daily biogas yield for the mesophilic reactors R1 and R3 reached a peak value of 1.99 L biogas with 1.22 L methane on the day

17 and 2.24 L biogas with 1.35 L methane on 14th day, respectively. To be specific it is important to know the total biogas and methane production and the cumulative biogas and methane productions, were calculated by summing daily biogas and methane production respectively. The cumulative biogas generation of the reactors R1 and R3 were 54.96 and 59.94 L/kg with 31.35 and 34.76 L/kg methane, respectively. The results depicted that the biogas and methane yields increased as the substrate concentration decreased from 15.18% TS to 7.68% TS. It can also be observed that mesophilic wet fermenter (7.68% TS of the substrate) produced more methane by 10.88% than mesophilic dry fermenter (15.18% TS of the substrate) during the studied fermentation period. Though hydrolysis and methanogenesis increased with the increase in the moisture content during anaerobic fermentation of cow dung and other organic solids, the comparable methane yields and organic material removal were observed for cow dung of initial substrate concentration from 7.68 to 15.18 TS.

The methane content was determined low during start up period and increased swiftly in all the functional reactors. The average methane content for the reactors R1 and R3 were determined 57.04% and 57.99% while the highest were 60.42% and 61.64%, respectively. It was shown that the addition of water could not improve the biogas quality because there were no significant variations in methane contents among different treatments. As previous studies (Bhattacharya and Mishra, 2005; Luning *et al.*, 2003) pointed that the quality of biogas was identical among dry fermentation processes and to the liquid fermentation process. The percentage of carbon dioxide for all the tests has increased and stabilized in between 25-40%. Hydrogen gas was detected in very small percentage (<1%) during start up phase and then decreased. Negligible percentage (<0.30%) of hydrogen gas was usually detected during rest of the fermentation period in all the tests. This might happene as all the available hydrogen gas was rapidly combined with CO_2 to produce methane by hydrogenotrophic methanogens and presence of high percentage of H_2-utilising methanogens. It was also found that the liquid fermentation process of cow dung produced more biogas and methane than dry fermentation process but the size of these fermenters had to be the double of the latter reactors. It should be noted that considerably high energy input to maintain mesophilic temperature condition for biological activities inside the fermenter was required in wet fermentation process.

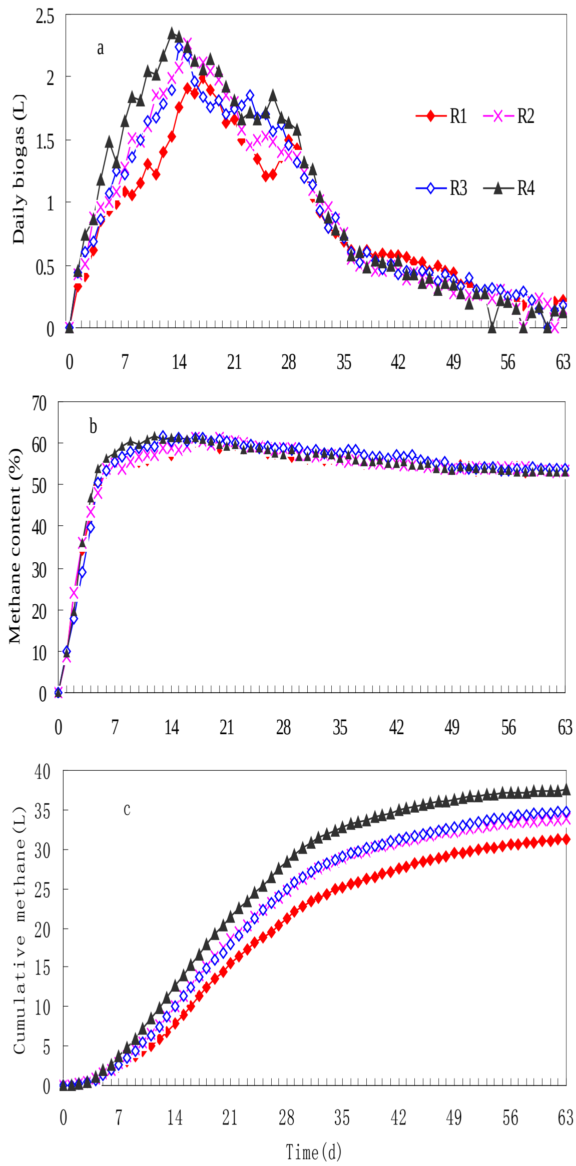

FIG. 5 (a) DAILY BIOGAS, (b) METHANE CONTENT AND (c) CUMULATIVE METHANE IN THE REACTORS.

Thermophilic Fermentation Process

Like mesophilic reactors, similar trends of daily biogas and methane yields were observed in the thermophilic reactors but the biogas production rate of the thermophilic fermenters observed was high. The daily biogas yield for the thermophilic reactors R2 and R4 reached a peak value of 2.26 L biogas with 1.32 L methane on 15th day and 2.35 L biogas with 1.45 L methane on the day 13, respectively. The cumulative biogas generation of the reactors R2 and R4 measured were 59.03 and 64.62 L/kg with 33.78 and 37.54 L/kg methane, respectively. It can be seen that volume of

biogas (about 10%) was recorded relatively higher in the thermophilic reactors than that of mesophilic reactors. It can also be observed that the thermophilic wet fermenter produced more methane by 11.13% than the thermophilic dry fermenter during the studied fermentation period. As like mesophilic fermentation, it was detected that comparable methane yield and organic materials removal were found during the thermophilic fermentation of cow dung of substrate concentration from 7.66% to 15.15% TS although the addition of water has prompted the start up period with early generation of biogas and biodegradability.

The methane content was determined low during start up period and increased swiftly in all the functional reactors. The average methane content for the reactors R2 and R4 were determined 57.23% and 58.09% while the highest were 61.13% and 61.58%, respectively. The reactor at thermophilic temperature generated higher cumulative biogas and cumulative methane compared to the reactor at the mesophilic temperature for the same initial solid contents in the feedstocks.It was also found that the liquid fermentation process of cow dung produced more biogas and methane than dry fermentation process but the size of these fermenters had to be the double of the latter reactors. It should be noted that considerably high energy input to maintain thermophilic temperature condition for biological activities inside the fermenter is required in wet fermentation process. Operating in the thermophilic temperature range was interesting because it led to faster reaction rates and higher gas production than that in mesophilic process but it was hard to maintain the process stable. The requirement of higher energy and presence of relatively free ammonia also limited the application of this process.

Organic Materials Removal

During the fermentation process, the organic matter can be distributed into the product (biogas) and the remaining unfermented material in the residue. It means the organic content of the waste is reduced with simultaneous production of biogas in a fermentation process. The efficiency of fermentation process was evaluated in terms of biological conversion of the substrates with VS or COD removal. FIG. 6 presents the VS and COD conversion efficiency for all the tests during the fermentation period. The values of VS and COD were high in the beginning and gradually decreased due to consumption by fermenting and methanogenic bacteria. The VS removal efficiency for the mesophilic reactors R1 and R3 were 50.01% and 56.33%, indicating that 12.64% organic material was converted into methane and carbon dioxide in the wet fermentation process of cow dung higher than that in the dry fermentation process of cow dung. Similarly, the VS removal efficiency of thermophilic fermenters R2 and R4 were 53.43% and 60.52%, respectively, demonstrating that 13.27% organic material was converted into methane and carbon dioxide in the wet fermentation process of cow dung higher than that in the dry fermentation process of cow dung.

Moreover, the thermophilic temperature could increase VS removal efficiency by 6.84% in the dry fermentation process and 7.44% in the wet fermentation process. There were close relationships

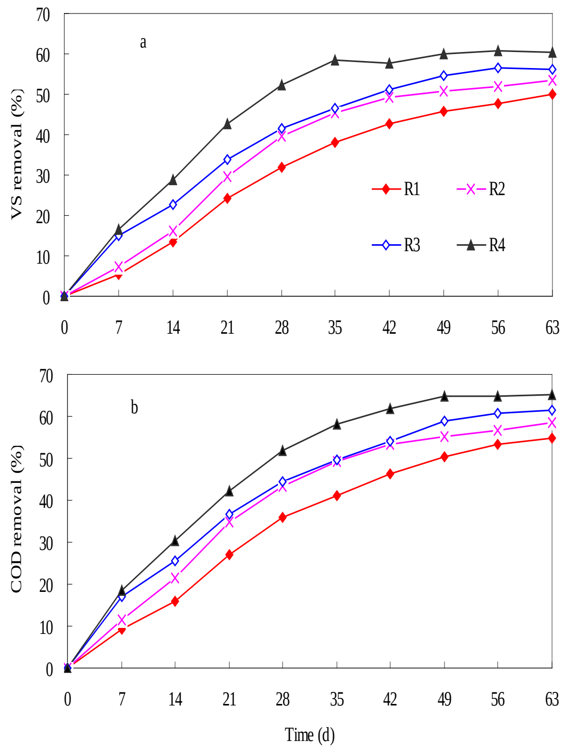

FIG 6. (a) VS And (b) COD Removal Efficiency.

between biogas yields and organic materials removal. The VS and COD removal efficiencies were determined greater in R4 followed by R3, R2 and R1. It can be shown that the VS and COD removal efficiencies of cow dung were higher in thermophilic temperature than those of in mesophilic temperature. Table 3 presents the organic material conversion efficiency and methane yield per gVSr and gCODr in

TABLE 3. ORGANIC MATTER DEGRADATIONS AND SPECIFIC METHANE YIELDS.

R	Organic matters & their conversion efficiencies						Methane yields	
	VS_i (g/kg)	VS_r (%)	COD_i (g/L)	COD_r (%)	$SCOD_i$ (g/L)	$SCOD_r$ (%)	L CH_4/gVS_r	L CH_4/gCOD_r
R1	122.53±0.4	50.01	142.41±5	54.99	60.32±0.6	69.46	0.333	0.271
R2	122.32±0.4	53.43	142.15±4	58.37	60.43±0.5	72.32	0.351	0.286
R3	68.53±0.3	56.33	78.35±3	61.35	34.22±0.4	73.63	0.345	0.285
R4	68.32±0.3	60.52	78.28±3	65.36	34.13±0.4	77.78	0.374	0.307

R: reactor, i: initial, r: removal

bio-methanization processes of cow dung with different initial total solids concentrations at the optimal mesophilic and thermophilic temperatures. The biodegradability was found to be 0.333, 0.351, 0.345 and 0.374 LCH_4/gVS_r in the functional fermenters R1-R4 while in terms of LCH_4/gCOD_r, it were 0.271, 0.286, 0.285 and 0.307, respectively. The biodegradability was found higher in thermophilic temperatures. It was also boosted with the addition of water as increase in moisture fuels in the hydrolysis of the substrate and consequently overall fermentation process. But the biodegradability in dry reactors was comparable to that of wet fermenters. Thus, dry fermentation process of cow dung is feasible process. Thermophilic temperature was able to prompt the biodegradation of the cow dung in both dry and wet type fermenters. It can be concluded that the fermentation performances were related to the TS concentration. Although high water content enhanced both methane production and biodegradability to some extent, it was observed that water activity of the manure was in favourable range for bacterial growth up to 15% TS content. Furthermore, the reaction rates achieved in dry fermentation process was competitive with conventional slurry type fermentation process.

Digestate Characteristics and Its Reuse

Apart from biogas, the methane fermentation process produces byproduct (digested residual) which can have a value as soil amendment. A major value of the manure is the nitrogen and phosphorous contents as fertilizer. This process offers an opportunity to recover and reuse a portion of the nutrient in the cow dung. Dry fermentation process results comparatively in a lower outcome of leachate. The TS of effluents from dry fermenters was about 11% while that for wet fermenters was about 5%. There is comparatively less chance of leachate flow inside ground water in case of dry fermentation process. Furthermore, the steps involving water addition before digestion and water removal after digestion were eliminated in the dry fermentation process, making the process technically simpler than conventional digestion. In general it has been observed that land required for composting of the digestate in wet fermentation process is relatively higher enough than that needed for the dry anaerobic digestate. Handling of the digestate is also convenient in case of dry fermentation process compared to that in wet fermentation process. Relatively liquid nature of the effluent in wet fermenters might cause non-point pollution problem on disposal. The nutrients, mainly nitrogen and phosphorus were higher in the digestate from dry fermenters compared to that from the liquid anaerobic fermenters.

Conclusions

As the comparable methane yields and organic materials removal were obtained in dry fermentation process of cow dung with the wet fermentation process at both mesophilic and thermophilic temperatures, it might be a promising substitute to the conventional process. In addition, no significant change in the quality of the biogas was detected

increasing initial total solid of cow dung from 7.68% to 15.18%. The higher total solid of the dry-digestate (10.87%) not only makes the handing of the digestate easier but also lowers the requirement of space for composting. In contrast, wet fermentation process required larger reactor volume and higher energy to maintain the temperature of the reactor for the same loading rate.

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